Reinforcement Assembly for Matrix Materials

This invention relates to an assembly of interlaced rods, suitable for use as embedded reinforcement in matrix materials such as cementitious, ceramic and synthetic resin matrices.

It is common to reinforce cementitious matrices such as concrete with embedded rods, usually of steel and often welded or otherwise constrained in the form of a grid arrangement. Other reinforcement arrangements have been used, such as steel sheet or perforated sheet, but these are less common.

Where the reinforced matrix is for use in blast and/or ballistic (i.e. projectile) impact resistant barrier structures, for example for use in battle zones or in locations near explosive hazard sites, or for secure containment, it is important that the reinforcement should contribute to dispersal of impact forces through the matrix away from the impact site, and hinder projectile penetration of the matrix. Hence there is a need for improved reinforcement assemblies which perform well in such circumstances.

Cementitious and ceramic matrices tend to be heavy, and are even heavier with embedded steel reinforcement. This is a disadvantage when the reinforced matrix material is intended to be portable or easily handled, for example in the form of reinforced panels for use as construction elements of strong and/or impact resistant structures. In such circumstances, it would be desirable to use lighter matrix materials such as synthetic resins. However, resin matrices offer poorer resistance to projectile impact than ceramics and cement-based materials, so the reinforcement used with resin matrices needs to be particularly effective to compensate. Using a higher proportion of steel reinforcement would be one way to achieve this, but that would negate the weight saving gained by using the resin matrix.

Hence there is a need for a reinforcement assembly which can be constructed of lightweight materials when necessary, but which nevertheless is effective in

conferring a high level of blast and/or impact resistance on the matrix in which it is embedded.

The present invention makes available such a reinforcement assembly, and shaped structures such as panels incorporating the assembly.

According to the invention, there is provided an assembly of interlaced rods, suitable for use as embedded reinforcement in matrix materials, comprising first, second and third layers of rods, the rods of each layer being orientated generally parallel to one another, the second layer being located between the first and third layers, the rods of the first and third layers being longitudinally orientated in the same direction, with those of the second layer being longitudinally orientated generally at right angles thereto, the rods of the first and third layers being paired such that each nth rod of the first layer, herein designated rod n_1, is paired with the nth rod of the third layer, herein designated rod n_3, paired rods of the first and third layers being drawn together under tension by a flexible filament wound between them in a series of runs spaced along the length of the rods of the first and third layers, each such run extending transversely to the longitudinal orientation of the rods, rods of the second layer being located generally parallel to and between adjacent transverse runs of filament, each such transverse run of filament comprising a forward and reverse sinusoidal winding which interlaces rods of the first and third layers, the forward sinusoidal winding following the pattern: rod $1_1 \rightarrow 2_3 \rightarrow 3_1 \rightarrow 4_3 \rightarrow \ldots$ and then continuing in the reverse sinusoidal winding pattern: $\ldots\ 4_1 \rightarrow 3_3 \rightarrow 2_1 \rightarrow 1_3$, whereby each pair of rods n_1 and n_3 in the first and third layers is enclosed by and drawn together by a loop of filament formed by the forward and reverse winding patterns.

The sinusoidal winding of filament which ties together the rods of the first and second layer may be performed manually but, being of a simple repeating pattern, it is easily adapted for implementation by machine. The layered rod arrangement and the filament winding pattern cooperate to make the assembly of the invention a particularly suitable reinforcement for matrix materials intended to defend against blast and impact resistance.

Between any adjacent pair of transverse runs of filament there may be a single rod of the second layer, or a plurality of rods of the second layer.

Each transverse run may be formed by one continuously wound filament, and in one embodiment all the transverse runs are formed by one and the same continuously wound filament.

Normally, the rod assembly will initially be assembled in a rectangular or square panel format, but by suitable selection of rod lengths and relative placement for filament interlacing, many alternative polygonal panel formats are also accessible, such as hexagonal and triangular arrangements. It is also possible to embed a rectangular or square rod assembly in a suitable matrix material, such as a synthetic resin (as discussed below) and, after hardening, to cut a section of any desired shape from the resultant embedded assembly using a laser cutter, for example. Where the resin-embedded rod assembly is faced with additional armour (again as discussed below), for example ceramic or metal plate armour, a laser cutter could also be used to cut a desired panel shape from the total assembly.

The filament may be in the form of a wire, a monofilament, or a multifilament string or rope, and the filament may comprise metal, for example steel, synthetic polymer, for example polypropylene or aramid resins, or carbon fibre. Rods of two or more material types may be present in the assembly, if desired.

In some of the embodiments of the invention, the rods of the assembly may be of metal, for example steel, or of fibre-filled resin wherein the fibres may be, for example synthetic polymer, glass, steel or carbon.

The rod assembly of the invention is primarily intended to be embedded in matrix material as reinforcement. In that case, it will normally be completely embedded, but assemblies which are partially embedded, or surface exposed, are not excluded. The assembly may find applications which do not involve

embedding in matrix material, for example in the construction of retaining walls for groundworks, to minimise earth or land slippage.

The matrix material including a rod assembly of the invention may be formed into a shaped article, for example a panel, if necessary by cutting the desired shaped panel from an initial matrix material-embedded blank.

The rod assembly of the invention may be embedded in any desired matrix material, but cementitious, ceramic and synthetic polymers will usually be the most common materials. Of those, the assembly offers distinct impact resistance advantages when embedded in synthetic polymer matrices, and also lightweight advantages when the rods are of fibre filled resin.

For highest levels of resistance to blast and/or projectile impact the rod assembly may be embedded in matrix material and additional reinforcement ion the form of additional plate or rod reinforcement may also be embedded or partially embedded therein in spaced or contiguous layered relationship to the rod assembly. Thus in one embodiment, a rod assembly of the invention may be embedded in synthetic resin matrix, and armour plate may be positioned on one or both sides of the rod assembly, either totally or partially embedded in the matrix.

In some embodiments, particularly where the rod assembly is embedded as reinforcement in a panel of matrix material, it may be desirable to include a flexible sheet material, for example a woven aramid mat, embedded or partially embedded in the matrix in spaced or contiguous layered relationship to the rod assembly. The panel may then be positioned with the sheet on the side opposite to that from which impact is anticipated, and the sheet acts as an anti-spalling element, reducing the risk of damage due to fragments of the matrix material flying off the panel after frontal impact.

In other embodiments, the rod assembly embedded in matrix material may be laminated as a backing to blast- or ballistic impact-resistant armour, for example armour plate or armour comprising an array of contiguous cells filled

with matrix material, for example a honeycomb structure of steel walled cells mounted on a backing plate, the cells being filled with hard cementitious, ceramic or resin matrix material, often including a high loading of fibres of synthetic resin, steel, glass or carbon.

In yet other embodiments the rod assembly embedded in matrix material may be laminated to a backing mass which crushes or deforms progressively under impact, for example a cellular or foamed material. With the reinforced matrix facing the direction of impact, it may then absorb much of the impact force, and the remainder being attenuated by the crushable or deformable backing mass.

The invention will now be further described and illustrated by reference to the Figures, wherein:

Fig.1 illustrates a simple rod assembly in accordance with the invention.

Fig 2 illustrates the rod assembly of Fig. 1 viewed in cross section in the direction of arrow A of Fig.1, showing the forward and reverse winding pattern of the first run of filament.

Fig 3 illustrates in cross section a panel of matrix material in which is embedded a rod assembly in accordance with the invention, the panel including an embedded layer of sheet material, and being bonded to an armour plate.

Fig 4. illustrates a form of armour plate which may be substituted for that of Fig 3, in the form of an array of contiguous cells filled with hard matrix material.

Fig 5. illustrates in cross section a panel of matrix material in which is embedded a rod assembly in accordance with the invention, the panel being laminated to a crushable cellular backing mass.

Referring first to Figs.1 and 2, simple rod assembly of the invention is shown. For simplicity of description, the assembly is shown as having only three rods 1_1, 2_1 and 3_1 in a first layer, paired with three rods in a third layer 1_3, 2_3, and 3_3, the rods of those layers being orientated generally parallel to one another. A second layer of two rods 2_1 and 2_2 is located between the first and third layers. Rods (1_1, 2_1, 3_1) and (1_3, 2_3, 3_3) of the first and third layers respectively are longitudinally orientated in the same direction, and rods (2_1, 2_2) of the second layer are longitudinally orientated generally at right angles thereto.

The rods may be of any material consistent with the reinforcement properties expected of the assembly.

Rod 1_1 is drawn together under tension with rod 3_1, 2_1 with 2_3, and 3_1 with 3_3 by a flexible filament, for example a multifilament string of aramid fibre, wound between them in a series of three runs r1, r2 and r3 extending transversely to the longitudinal orientation of rods (1_1, 2_1, 3_1) and (1_3, 2_3, 3_3). Rod 2_1 is parallel to and between runs r1 and r2, and rod 2_2 is parallel to and between runs r2 and r3.

As is perhaps best shown in Fig.2, the filament is tied and knotted at 4 to rod 1_1 for the start of run r1, which is created by forward and reverse sinusoidal windings under tension which interlace rods (1_1, 2_1, 3_1) and (1_3, 2_3, 3_3). The forward winding from left to right follows the pattern: rod $1_1 \rightarrow 2_3 \rightarrow 3_1$ and then continues in the reverse right to left winding pattern: $3_3 \rightarrow 2_1 \rightarrow 1_3$. Paired rods of the first and third layers are encircled and drawn together by the loops of filament formed by the forward and reverse winding patterns. On completion of run r1, the filament passes over rod 1_2 at 5 for run r2 the forward winding following the pattern $1_3 \rightarrow 2_2 \rightarrow 3_3$, and the reverse winding following the pattern $3_1 \rightarrow 2_3 \rightarrow 1_1$. Then the filament passes behind rod 22 at 6 to commence run r3, which follows the forward and reverse winding patterns of run r1. The winding process just described would be continued if there were more rods in the second layer. The effect of drawing together rods (1_1, 2_1, 3_1) and (1_3, 2_3, 3_3) by filament runs r1, r2 and r3 is to trap rods (2_1, 2_2) securely in

their position between the first and third layers of rods and individually between adjacent filament runs.

It will be apparent that although in Figs. 1 and 2 the filamentary runs all start at rod 1_1 the choice of start point is arbitrary.

For ease of understanding, the rod assembly described by reference to Figs. 1 and 2 has only three rods in each of the first and third rod layers, and two in the second layer. In practice, many more rods would be present in each layer. Furthermore, In Figs. 1 and 2 only one rod of the second layer is positioned between adjacent filament runs r1-r2 and r2-r3, but in other embodiments of the invention it may be preferred to position two or even more second layer rods between some or each pair of adjacent runs.

The rod assemblies of the invention, constructed according to the principles illustrated in Figs. 1 and 2, may be embedded in matrix material, for example of cementitious, ceramic or synthetic resin materials. Resin materials will often be preferred for their lighter weight. Cementitious matrix materials include the DSP ("Densified systems containing ultrafine Particles") matrix materials disclosed, e.g., in US Patents Nos. 5,234,754 and 4,588,443 which may be based on dense packing of cement particles with ultrafine particles, for example silica fume particles, in interstices between the cement particles. A preferred matrix, is made from a mix containing cement particles, ultrafine microsilica particles of a size which is typically about 1/100 of the size of the cement particles, water in a low amount relative to the cement plus microsilica, a concrete superplasticizer as dispersing agent, and silica or carborundum sand, often with added steel fibres. Typically, DSP matrices may have compressive strength in the range 200 to 400 MPa, tensile strength in the range 10 to 50 MPa, modulus of elasticity in the range 30 GPa to 100 GPa, and fracture energy in the range 1 KN/m to 100 KN/m.

Whatever the matrix material chosen, the rod assembly will be embedded by immersing the assembly in the matrix material while in fluid form, and then setting or allowing it to set. Shaped articles may be formed by use of suitable

moulds to contain the fluid matrix material while embedding the assembly and setting.

In Fig 3, a rod assembly 7 constructed according to the principles illustrated in Figs. 1 and 2 but with many more rods in each of the three layers of Figs 1-3 is shown in cross section, embedded in a matrix material 10 and shaped as a panel of rectangular cross section. A sheet material 11 for example a woven mat of aramid fibre, is embedded in the matrix material close to the back surface of the panel. This is achieved by lining the bottom of the panel mould with the woven mat prior to pouring in the unset fluid resin mix, so that as the resin sets the mat becomes embedded. Also shown in Fig. 3 is a steel plate 12 located on the face of the panel. The plate has studs 13 fixed, for example by welding or gluing to the side adjacent the resin matrix. These studs serve to anchor the studs in the matrix to improve adhesion between plate and matrix. The plate is simply pressed onto the exposed surface of the resin while still fluid in the panel mould, and becomes firmly fixed as the resin sets. The resultant panel is useful as an element of an armoured protective barrier. The armour plate faces the direction of the impact threat, the rod assembly provides back-up reinforcement of the matrix material on deformation or penetration under impact. The sheet material 11 serves as an anti-spalling guard to contain fragmentation from the rear face of the panel under such deformation or projectile impact.

Fig. 4 shows part of a blast- or ballistic impact-resistant armour plate comprising contiguous cells 15 filled with hard matrix material 16, the cells being defined by containing walls 17 mounted on a backing plate 18. The cell walls and backing plate may be of metal such as steel or of resinous material. The hard matrix material may be cementitious, ceramic or resinous, and may be filled with reinforcing fibres, for example of metal such as steel, synthetic polymer or carbon. The armour plate of Fig 4 may be laminated to the face of a matrix material panel in which a rod assembly of the invention is embedded, in the same way as the plate 12 of Fig. 3.

Fig. 5 shows, in partial cross section, a matrix body 20 of, for example resinous material, in which is embedded a rod assembly 21 of the invention, the whole being backed by a crushable backing mass 22 of cellular material such as foamed polystyrene. The backing mass in turn is backed by a containment sheet 23 of, for example stiff paperboard. The resultant assembly may be used as a crash barrier, since the reinforced matrix will absorb the bulk of the impact energy, and the resultant deformation of the matrix will crush the backing mass thereby attenuating the remaining impact forces.